CHAPTER 12

Subadult Growth and Development

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Introduction

Growth and developmental status is often used as an indicator of general health status at the population level. A brief review of literature regarding human skeletal growth and development indicates there are several methodologies for assessing these processes in human skeletal remains (Albert and Greene 1999; Flecker 1942; Goode et al. 1993; Gruelich and Pyle 1950; Hoppa 1992; Hoppa and Fitzgerald 1999; Hoppa and Gruspier 1996; Johnston and Zimmer, 1989; Livshits et al. 1998; Miles and Bulman 1994; Saunders 1992; Saunders et al. 1993; Sciulli 1994; Todd 1937). Particularly, adult height may be used as a proxy for an individual's general state of childhood and adolescent nutritional status (Goode et al. 1993; Hoppa 1992; Miles and Bulman 1994). However, Hoppa (1992) and Miles and Bulman (1994) have recently proposed the use of cross-sectional long bone growth profiles in archaeological populations as a means to assess a population's health status, using long bone lengths would stand as a proxy for stature estimates for immature remains. On the other hand, Goode et al. (1993) propose standardizing (see below) all long bone measurements as a method of representing any or all long bones measured in a single graphic plot. This method was promoted as a means of: 1) circumventing situations wherein infant and child skeletons are either fragmentary or skeletal elements are not equally represented, 2) promoting intra- and interpopulation growth comparisons, and 3) as a means of diagnosing individuals with grossly deviant standardized values for closer analysis of the abnormality (1993:323)[1.]

A more thorough discussion of literature that pertains to studies relating long bone lengths to health status can be found in Goode-Null (2002), Hoppa (1999), and Miles and Bulman (1994). Previously, many such analyses of long bone lengths were used to predict the age of unknown individuals (Jantz and Owsley, 1984; Ubelaker 1989). However Hoppa's study revealed that diaphyseal long bone lengths were too variable when comparing four populations across temporal and geographic contexts. His study also illustrated the complex relationship between environment and the biology of growth by comparing age estimates based on humeral and femoral lengths for seven geographically and temporally disparate populations. Hoppa's conclusion was that standards for diaphyseal length were capable of grossly under- or overestimating the age of immature individuals.

The overarching goal of this chapter is to produce an anthropologically-grounded body of information that will broaden our knowledge about the life experiences of enslaved African children in New York City. Specific chapter objectives are to: 1) assess the growth status of individuals; and 2) compare growth status– a) between the sexes, where appropriate and b) with other indicators of health and well being, specifically those associated with physical activity/labor, to achieve a more holistic perspective of childhood under enslavement. These objectives lend themselves to addressing the following more general question about life in the African/African American community of eighteenth century New York City: How did the institution of slavery affect the overall health and well being of the children in the NYABG population?

Due to the often fragmentary and variable representation of skeletal elements of these individuals, it has been necessary to focus predominantly on growth, osteometric data analysis, in relation to health status and biomechanical stressors. However, development is partially addressed in relation to biomechanical stressors and the high incidence of craniosynostosis (premature fusion of the sutures in the cranium) diagnosed in this population. Given the extensive nature of the New York African Burial Ground Project (NYABGP), skeletal development will be analyzed in future studies and publications related to skeletal developmental asymmetry.

Methodology

The overall condition of the skeletal remains from this site ranges from poor to excellent. The assessment presented in this chapter consisted of the analysis of metric and nonmetric data collected according to the *Standards for Data Collection from Human Skeletal Remains* (Buikstra and Ubelaker 1994). The data include but are not limited to: dental and skeletal age (e.g., epiphyseal closure), sex (adults), pathology, trauma, and osteometrics. These data have been recorded and entered into an SPSS 10.0 Graduate Student Statistical Package database and were used in the analysis presented here.

The methodologies employed in the analysis of growth relied upon building a baseline population sample from which subsamples could be drawn for specific statistical tests. Therefore, the methodological section of the chapter will first delineate how the baseline sample was selected and will be followed by more specific descriptions of how subsamples were drawn.

Criteria for Baseline Sample Size

Several criteria for determining which individuals could be included were employed in the construction of a baseline sample for this study. First and foremost, only those individuals for whom age assessments could be made were included. Secondly, age assignment had to have been based on either dental ages (for individuals less than 15-20 years) or pelvic ages (for individuals 17 years and older), or more than one aging method if the individual was an adult without a pelvic age assessment. Age assessments for infant and juvenile remains were restricted to dental sequences as they exhibit the highest correlation with chronological ages (Lewis and Garn, 1960; Demirjian, 1986; Smith, 1991). Additionally, dental ages are more highly correlated between sexes than either epiphyseal union or long bone lengths. Specifically, skeletal development remains relatively androgynous until the onset of testosterone production in the 6-8 week old male embryo (Pryor 1923; Tanner 1990). At this point the female embryo continues to develop skeletally at a fairly steady rate, while males begin to lag. This sexually differentiated pattern of development progresses from days to weeks during fetal life, and then to months postnatally (Pryor 1923; Pyle and Hoerr 1955). Similar reasoning underlies the preference for utilizing pelvic morphology as the primary indicator of age in older subadults and adults. However, it was deemed appropriate to utilize mean age assessments for two or more aging techniques in the absence of pelvic age indicators. This is predicated upon the higher probability of being able to apply alternative aging methods in a sex specific manner when assessing older subadults and adults. [2] Due to the criteria used for constructing this baseline sample, there may be some inconsistencies in the ages reported for some individuals between this and other chapters when results of the analysis are presented and discussed.

Criteria used for baseline selection resulted in a maximum possible sample of 349 individuals from which subsamples for specific analyses could be drawn. Of these 349 individuals, 153 were adults and 194 were less than 25 years of age (172 were 20 years of age or less, and 135 were less than 15 years of age), and thus available as a baseline subsample to specifically assess growth status within the skeletally immature segment of the population.

Growth

Considerable data relating to human growth and development was collected and entered into the project database. These data include dental development, epiphyseal union scores, and long bone measurements, which have been utilized to calculate composite ages for all individuals. This study used the existing ABGP database to meet the objective of assessing overall and differential childhood health and well being of the New York African Burial Ground (NYABG) immature individuals *vis a vis* growth. To achieve this objective, data related to demographic trends in growth status were analyzed separately and in conjunction with data related to pathologies/biomechanical stress indicators, and trauma (see below).

A critique of long bone growth profiles recommends the following methods to assess growth in this population: 1) standardized long bone measurements (Goode et al.1993; Sciulli 1994), and 2) stature estimation. It is generally understood that, for both males and females, skeletal maturity (cessation of growth and union of secondary growth centers) under optimal conditions is usually attained at about twenty years of age

(21 years for males, 18 years for females). Thus, to adequately assess growth status in this population, all individuals under the age of 25 years (n=194) and who are represented by postcranial remains comprised the base sample for data collection. The number of individuals that have sufficient aging criteria and long bones (minimally) that can be included in this portion of the analysis is 130. Of these 130 individuals, 48 are younger than 25 years.

Long Bone Length Standardization

Long bone measurements have been standardized for growth assessment using a very simple ratio calculation. Once age (specifically dental) determination is completed, diaphyseal length of a long bone is divided by the appropriate for age diaphyseal length found in one of the available growth standards. For example: Burial 96 is designated as a male with composite pelvic age of 17 years. His femoral length is 43 cm, while the Maresh (1970, see below) standard indicates an average femoral length of 50.89 cm for males age 17 years. Thus, the resulting proportion, signified by δl is 43/50.89 or 0.845. Thus, if an individual is represented by a single long bone (δl_i) or by multiple long bones, they can be represented in the plot of δl_i for the population (for additional information on computing δl values see: Goode et al. 1993). For those individuals represented by more than one long bone a mean value of the δl_i for all separate long bones, designated δl_{mean}, can be calculated and plotted. As Goode et al. (1993) indicate, a δl_i greater than unity would represent a bone (or bones if δl_{mean}) that is (are) longer than the standard value, while the opposite is true for δl_i and/or δl_{mean} values less than unity.

The standard used to test this method is derived from the long bone data series collected by the Child Research Council of Denver, Colorado on living children, as originally reported on by Maresh in 1955 (*cf*. Goode et al. 1993). However, the Denver research group continued to collect data until 1967, and Maresh provided an updated version of the data used by this method in 1970. The updated data reported on by Maresh has recently (Scheuer and Black 2000) been republished and is easily accessible, which promotes the use of this method for interpopulation comparisons, as well as further testing of the method itself to delimit its explanatory power in relation to skeletal growth across time and space.

One such test of the standardization of long bone measurements is provided by Sciulli (1994). Sciulli also utilized the same standard for long bone lengths (Maresh 1955) to calculate δl_i and subsequent δl_{mean} values. However, he substituted Fazekas and Kośa's (1978) long bone data at 10 lunar months for Maresh's data for 2 months in the birth cohorts of the populations being tested.

Perhaps the most significant contribution of Sciulli's test, of the standardized long bone measure technique, is his finding that not all δl_i were equivalent, "and therefore the magnitude of the overall measure δl_{mean} depends on which long bone(s) contribute to it" (1994:257). This conclusion is based on two tests he performed. First, Sciulli plotted and compared Maresh's long bone lengths. This resulted in observing that the femur has the greatest growth velocity rate, followed by the tibia and fibula, which were similar. These were followed by the humerus, then the radius and ulna, which were also similar and showed the slowest growth rates. Secondly, Sciulli demonstrated that the five Native American samples in his test of the method "show a significant concordance in relative long bone length" (1994:258). This concordance indicates that, for these samples, elements rank from smallest to largest in length relative to the Maresh standards in the following manner: femur, tibia, fibula, humerus, radius and ulna (equally large). Sciulli concluded that the pattern found in relative long bone lengths for the five Native American samples can be explained if one accepts the hypothesis that "the most rapidly growing long bones will be the most greatly affected by nutritional and disease stress" (1994:258). Otherwise, he concludes that the patterns observed in his test of the method may be due to inherent differences in growth patterns of the long bones of Native Americans and those of the reference population.

Sciulli's latter point will be addressed below. However, it is important to note that Maresh's data on long bone lengths are based on a sample composed of 123 males and 121 females who participated in this longitudinal (1930-1967) health study from birth until at least 18 years of age. These children are of White European descent (primarily Northern European), and are from families whose socio-economic status is characterized as middle-to-upper middle class. The logic behind recruiting children from such families was: 1) to insure that parents had a sufficient understanding of the project goals to maintain a long term commitment, 2) private medical care was available to the participants to reduce the influence of project staff over their health care, and 3) that adequate food resources were not economically dependent (McCammon 1970:6).

The decision to use this reference population in standardizing long bone measurements for the NYABG population was predicated upon several Factors. First, it will facilitate comparisons with previous studies. Second, the genetics of human growth and particularly development are the same for all populations. Specifically, a subset of developmental genes, known as homeobox genes, is essentially "phylogenetic" genes, and thus more highly canalized (under stricter biological control). These homeobox genes are responsible for controlling segmentation and sequencing of other genes during development (Mange and Mange 1988; Weiss 1993). On the other hand, genes controlling growth are much more plastic, or susceptible to environmental impacts (CDC/NCHS 2001: http://128.248.232.56/cdcgrowthcharts/module2/text/page5b.htm). Here it is necessary to be explicit regarding the meaning of the terms growth and development. Acheson (1966:465) notes that growth is "the creation of new cells and tissues" while maturation/development "is the consolidation of tissues into permanent form." These definitions are reiterated by Bogin (1999) when he notes that growth is a change in size, while development refers to a change in shape.

Consequently, secular trends in growth within and between populations, such as those reported by Sciulli (1994), have a stronger relationship to environmental factors such as political-economic conditions or hypoxic stress. Therefore, this reference population acts as a gold standard, providing an opportunity to assess the level of impact that the political-economy of enslavement had on the growth of the NYABG children. Lastly, this is one of the few longitudinal growth studies undertaken in an environment with a naturally occurring stressor–namely high altitude. In addition to chronic exposure to hypoxic stress, McCammon's (1970:23-38) description of the population included sufficient background information related to the incidences, types, and timing of illnesses experienced by these children to indicate that there was exposure to short and long term health stressors that could negatively impact the growth of at least some of the children in this study. This, finding then, offsets to some extent the critique that the applications of growth standards derived from homogeneous populations do not adequately reflect the variety of natural and social conditions experienced by populations that do not meet the same demographic and/or epidemiological composition. This point will be revisited in the following section. In this study the method for calculating standardized long bone measures (δl_i and δl_{mean}) as described by Goode et al., (1993) was followed. However, as outlined by Sciulli, long bone measures provided by Fazekas and Kośa (1978) were utilized to calculate the standardized long bone measures in fetal and neonatal remains. Additionally, all individuals under the age of 25 years were included to verify the potential for diagnosing "catch-up" growth with this method when applied to cross-sectional data. Where possible, results from this analysis are compared to those of Goode et al., (1993) and Sciulli (1994).

Stature

Stature estimates for adults were calculated using regression formulae for African-American males and females as developed by Trotter (1970; *cf.* Ubelaker 1989; see Table 12.1). Fazekas and Kośa's (1978:264) non-sex specific regression formulae, as seen in Table 12.2, for fetal and neonatal recumbent length were used to estimate the measurements for fetal remains. It should be noted that Table 12.1 does indicate the standard error of the stature estimate per long bone, while Table 12.2 does not do so. The per long bone standard errors for fetal and neonatal recumbent length estimates are not provided by Fazekas and Kośa[3].

Table 12.1: African-American Stature Regression Formulae as Developed by Trotter (1970; *cf* Ubelaker 1989)

MALE		FEMALE	
Humerus:	Length(cm) × 3.26 + 62.10 ± 4.43	Humerus:	Length(cm) × 3.08 + 64.67 ± 4.25
Radius:	Length(cm) × 3.42 + 81.56 ± 4.30	Radius:	Length(cm) × 2.75 + 94.51 ± 5.05
Ulna:	Length(cm) × 3.26 + 79.29 ± 4.42	Ulna:	Length(cm) × 3.31 + 75.38 ± 4.83
Femur:	Length(cm) × 2.11 + 70.35 ± 3.94	Femur:	Length(cm) × 2.28 + 59.76 ± 3.41
Tibia:	Length(cm) × 2.19 + 86.02 ± 3.78	Tibia:	Length(cm) × 2.45 + 72.65 ± 3.70
Fibula:	Length(cm) × 2.19 + 85.65 ± 3.53	Fibula:	Length(cm) × 2.49 + 70.90 ± 3.80

Table 12.2: Fetal and Neonate Stature Regression Formulae as Developed by Fazekas and Kosa (1978)

FETAL/NEONATE REGRESSION FORMULAE	
Humerus:	Length(cm) × 7.52 + 2.47
Radius:	Length(cm) × 10.61+ 3.95
Ulna:	Length(cm) × 8.20 + 2.38
Femur:	Length(cm) × 6.44 + 4.51
Tibia:	Length(cm) × 7.24 + 4.90
Fibula:	Length(cm) × 7.59 + 4.68

The utilization of formulae provided by Trotter and Fazekas and Kośa provides opportunities for comparative analyses with previous studies of enslaved Africans and African Americans.

Only recently has a study been done using regression formulae for estimating the stature at death for juvenile and subadult remains. In the present study we utilize a sex specific and composite sex linear regression formulae for the calculation of estimated stature for immature remains (see Tables 12.3, 12.4, and 12.5). The regression formulae were constructed by using the National Center for Health Statistics (NCHS[4] 2000) recumbent length (infant) and stature data (children two to twenty years of age), as the dependent variable and growth series data for long bones (Maresh 1970), as the predictive or independent variable (Goode-Null, 2002). The utilization of these reference data sets to compute the regression formulae and apply them to the NYABG remains is based upon the fact that secular trends in growth are highly correlated with environmental conditions, as mentioned previously. Specifically, the CDC/NCHS states they "[p]romote one set of growth charts for all racial and ethnic groups. Racial- and ethnic-specific charts are not recommended because studies support the premise that differences in growth among various racial and ethnic groups are the result of environmental rather than genetic influences" (http://128.248.232.56/cdcgrowthcharts/module2/text/page5b.htm).

All regression equations were applied in a sex specific manner, if appropriate, to both mean long bone lengths and individual long bone lengths. For individuals of indeterminate sex, the composite regression formulae for birth < 12 months, and ≥12 months < twelve years were applied. Individuals over the age of twelve years were assessed by calculating male and female stature estimates; which were then averaged to achieve a mean height at death. Stature was computed for a total of 132 individuals from the NYABG population. Comparisons to the CDC growth standards were then undertaken for stature estimates for all individuals under age 25 years for whom age assessments were made (n = 48).

Development

As noted previously, the extensive nature of the ABGP and the fragmentary and variable representation of skeletal elements did not support an analysis of development at this time. Future studies are planned for such an analysis when additional data can be collected from radiographic films. However, it was possible to undertake a brief qualitative examination and discussion in relation to the presence of craniosynostosis. Craniosynostosis was observed in a total of 15 individuals under the age of twenty-five years. This high rate of occurrence will be examined in relation to primarily potential biomechanical, and to a lesser extent nutritional and genetic, stressors or causes.

Table 12.3: Regression Formulas for Calculating Stature of the Immature Remains of Male Children (all measures are in centimeters)

REGRESSION FORMULAS FOR JUVENILE STATURE ESTIMATION: MALE	
Humerus	
0 < 12mo:	Length × 7.50 + 1.72 ± 2.34 ($p < .05$, $r^2 = .995$)
≥ 12mo < 84mo:	Length × 4.66 + 26.71 ± .53 ($p < .001$, $r^2 = .999$)
≥ 84mo < 150mo:	Length × 4.54 + 29.66 ± .80 ($p < .001$, $r^2 = .999$)
≥ 150mo < 186mo:	Length × 4.42 + 25.41 ± 3.93 ($p < .001$, $r^2 = .996$)
≥ 186mo:	Adult formula
Radius	
0 < 12mo:	Length × 9.25 + 1.7 ± 3.29 ($p < .05$, $r^2 = .990$)
≥ 12mo < 84mo:	Length × 6.43 + 23.42 ± .49 ($p < .001$, $r^2 =1.00$)
≥ 84mo < 150mo:	Length × 6.07 + 29.41 ± .85 ($p < .001$, $r^2 = .999$)
≥ 150mo < 186mo:	Length × 5.72 + 28.40 ± 3.52 ($p < .001$, $r^2 = .997$)
≥ 180mo:	Adult formula
Ulna	
0 < 12mo:	Length × 8.88 - 2.87 ± 2.64 ($p < .05$, $r^2 = .995$)
≥12mo < 84mo:	Length × 6.07 + 20.23 ± .54 ($p < .001$, $r^2 =1.00$)
≥ 84mo < 150mo:	Length × 5.68 + 27.41 ± 1.04 ($p < .001$, $r^2 = .999$)
≥150mo < 186mo:	Length × 5.23 + 32.23 ± 2.87 ($p < .001$, $r^2 = .998$)
≥186mo:	Adult formula
Femur	
0 <12mo:	Length × 4.59 + 16.27 ± 2.49 ($p < .05$, $r^2 = .990$)
≥ 12mo < 84mo:	Length × 2.97 + 35.85 ± .39 ($p < .001$, $r^2 = 1.00$)
≥ 84mo < 150mo:	Length × 2.85 + 39.19 ± .57 ($p < .001$, $r^2 = 1.00$)
≥ 150mo < 216mo:	Length × 3.14 + 16.13 ± 3.55 ($p < .001$, $r^2 = .995$)
≥ 216mo:	Adult formula
Tibia	
0 < 12mo:	Length × 6.54 + 8.62 ± 5.93 ($p < .05$, $r^2 = .960$)
≥ 12mo < 84mo:	Length × 3.64 + 36.03 ± .37 ($p < .001$, $r^2 = 1.00$)
≥ 84mo < 150mo:	Length × 3.40 + 42.10 ± .70 ($p < .001$, $r^2 = .999$)
≥ 150mo < 216mo:	Length × 3.79 + 13.43 ± 2.07 ($p < .001$, $r^2 = .998$)
≥ 216mo:	Adult formula
Fibula	
0 < 12mo:	Length × 6.77 + 9.08 ± 4.98 ($p <.05$, $r^2 = .971$)
≥ 12mo < 84mo:	Length × 3.59 + 37.38 ± .43 ($p <.001$, $r^2 =1.00$)
≥ 84mo < 150mo:	Length × 3.56 + 38.92 ± .71 ($p <.001$, $r^2 = .999$)
≥ 150mo < 216mo:	Length × 3.79 + 19.67 ± 2.75 ($p < .001$, $r^2 = .997$)
≥ 216mo:	Adult formula

Table 12.4: Regression Formulas for Calculating Stature of the Immature Remains of Female Children (all measures are in centimeters)

REGRESSION FORMULAS FOR JUVENILE STATURE ESTIMATION: FEMALE	
Humerus	
0 < 12mo:	Length × 7.49 + 0.92 ± 2.76 ($p < .05$, $r^2 = .993$)
≥ 12mo < 84mo:	Length × 4.70 + 25.63 ± .63 ($p < .001$, $r^2 = .999$)
≥ 84mo < 150mo:	Length × 4.63 + 27.68 ± 1.62 ($p < .001$, $r^2 = .998$)
≥ 150mo:	Adult formula
Radius	
0 < 12mo:	Length × 10.45 - 5.05 ± 3.36 ($p < .05$, $r^2 = .992$)
≥ 12mo < 84mo:	Length × 6.57 + 22.99 ± .81 ($p < .001$, $r^2 = .999$)
≥ 84mo < 150mo:	Length × 6.11 + 30.66 ± 1.30 ($p < .001$, $r^2 = .998$)
≥ 150mo:	Adult formula
Ulna	
0 < 12mo:	Length × 10.06 - 10.52 ± 3.24 ($p < .05$, $r^2 = .993$)
≥ 12mo < 84mo:	Length × 6.13 + 19.90 ± .88 ($p < .001$, $r^2 = .999$)
≥ 84mo < 150mo:	Length × 5.60 + 29.70 ± 1.45 ($p < .001$, $r^2 = .998$)
≥ 150mo:	Adult formula
Femur	
0<<12mo:	Length × 4.49 + 15.90 ± 1.94 ($p < .05$, $r^2 = .994$)
≥12mo <84mo:	Length × 3.01 + 34.15 ± .56 ($p < .001$, $r^2 = .999$)
≥84mo < 144mo:	Length × 2.88 + 38.49 ± 1.16 ($p < .001$, $r^2 = .999$)
≥144mo:	Adult formula
Tibia	
0 < 12mo:	Length × 6.69 + 6.72 ± 5.58 ($p < .05$, $r^2 = .965$)
≥ 12mo < 84mo:	Length × 3.70 + 34.39 ± .55 ($p < .001$, $r^2 = .999$)
≥ 84mo < 144mo:	Length × 3.34 + 43.68 ± 1.49 ($p < .001$, $r^2 = .998$)
≥ 144mo:	Adult formula
Fibula	
0 <12mo:	Length × 6.90 + 7.62 ± 5.71 ($p < .05$, $r^2 = .963$)
≥ 12mo < 84mo:	Length × 3.65 + 35.98 ± .65 ($p < .001$, $r^2 = .999$)
≥ 84mo < 144mo:	Length × 3.58 + 38.69 ± 1.28 ($p < .001$, $r^2 = .998$)
≥ 144mo:	Adult formula

Table 12.5: Regression Formulas for Calculating Stature of the Immature Remains of Indeterminate Children (all measures are in centimeters)

REGRESSION FORMULAS FOR JUVENILE STATURE ESTIMATION: INDETERMINATE	
Humerus	
0 < 12mo:	Length $\times$ 7.51 + 1.17 ± 2.16 ($p < .001$, $r^2 = .990$)
≥ 12mo < 144mo:	Length $\times$ 4.70 + 25.63 ± .63 ($p < .001$, $r^2 = 1.00$)
Radius	
0 < 12mo:	Length $\times$ 9.69 - 0.73 ± 2.58 ($p < .001$, $r^2 = .987$)
≥ 12mo < 144mo:	Length $\times$ 6.57 + 22.99 ± .81 ($p < .001$, $r^2 = .998$)
Ulna	
0 < 12mo:	Length $\times$ 9.32 - 5.67 ± 2.49 ($p < .001$, $r^2 = .990$)
≥ 12mo < 144mo:	Length $\times$ 6.13 + 19.90 ± .88 ($p < .001$, $r^2 = .999$)
Femur	
0 < 12mo:	Length $\times$ 4.54 + 16.08 ± 2.29 ($p < .001$, $r^2 = .980$)
≥12mo <144mo:	Length $\times$ 3.01 + 34.15 ± .56 ($p < .001$, $r^2 = .999$)
Tibia	
0 < 12mo:	Length $\times$ 6.63 + 7.51 ± 3.55 ($p < .001$, $r^2 = .967$)
≥ 12mo < 144mo:	Length $\times$ 3.70 + 34.39 ± .55 ($p < .001$, $r^2 = .999$)
Fibula	
0 <12mo:	Length $\times$ 6.87 + 8.25 ± 3.17 ($p < .001$, $r^2 = .973$)
≥ 12mo < 144mo:	Length $\times$ 3.65 + 35.98 ± .65 ($p < .001$, $r^2 = .999$)

These results were also compared to data available in the project database regarding trauma and non-disease pathologies related to biomechanical stressors in an attempt to assess explanatory relationships in an age and sex specific manner. Specifically, long bone fractures were assessed in relationship to individual growth status, as were the non-disease pathologies of arthritic lesions, enthesopathies and hypertrophies. Also, generalized non-specific infectious lesions and anemias were correlated with stature to assess how differential access to nutritional resources may have impacted the growth of individuals in the New York African Burial Ground. All data analysis was accomplished using SPSS 10.0 Graduate Student Statistical Package for Windows. Specific tests utilized included chi square and correlations, with significance levels set at 5 percent ($p = 0.05$). Power analyses were performed to determine the probability of detecting type II (beta) errors (Hodges and Schell 1988). The power values, provided in Table12.6, were calculated for small ($w = 0.10$), medium ($w = 0.30$), and large ($w = 0.50$) effects for the specific subsample sizes.

Table 12.6: Power Values for Statistical Chi-square Tests based on sub-sample sizes and magnitude of effect (Effect size is denoted by w)

Sample	**N**	**w = 0.10**	**w = 0.30**	**w = 0.50**
Total Subsample	48	0.1065	0.5472	0.9337
Males	3	0.0534	0.0815	0.1393
Females	5	0.0557	0.1029	0.2010
Indeterminate	40	0.0969	0.4751	0.8854
0 < 6 years	30	0.0850	0.3759	0.7819
≥6 < 16 years	10	0.0615	0.1578	0.3526
≥ 16 < 25 years	8	0.0592	0.1357	0.2930

Analysis

There is a longstanding recognition of the synergistic relationships between 1) growth, 2) access to nutritional resources, and 3) chronic or acute infectious states (for example see Goodman 1992; Rankin-Hill 1997). However, few assessments of children in the archaeological record have included more than cursory examinations of activity-related skeletal indicators that integrate this triad of health factors. Therefore, the analysis presented below includes biomechanical indicators of stress as a means of enhancing the overall understanding of children's lives by creating a quartet of interrelated factors and indicators of health. As noted previously, 48 individuals comprise a population subsample in the analysis presented below relating to growth status, health, and labor.

Growth Assessment

Growth assessment provides an entry point for gaining a better understanding regarding what is impacting the distribution of deaths and life expectancies of the young adults, children, and infants from the New York African Burial Ground. The research presented here focuses on standardized long bone lengths and stature estimations. Preliminary growth evaluations for these individuals consist of comparing all individuals represented by the major long bones of the extremities to modern growth standards for height. This was done for both individual long bone elements, as standardized measures, and stature estimates.

Standardized Long Bone Measures

Long bone standardization is a relatively new method for assessing human growth from cross-sectional data that biological anthropologists often investigate. As was presented above, the method of standardization is a simple ratio (δl_i or δl_{mean}) of specific long bones to a corresponding growth standard by element. Table 12.7 provides the δl_i and sex specific δl_{mean} values for the total population subsample (N=48). As can be seen this table also provides the actual number of available elements by sex for calculation of the ratio. This table illustrates that Sciulli's (1994) conclusion that various long bones contribute differentially to δl_{mean}, is correct. When the chart in Figure 12.1 is consulted, it is obvious that this method does not allow the diagnosis of catch-up growth (accelerated adolescent growth that can greatly compensate for childhood growth retardation) in this population. However, Sciulli's (1994) conclusions that environmental factors will more likely affect the long bones with the most rapid growth velocity may be valid for this population. Table 12.7 indicates that of the sex specific calculations the

Table 12.7: δl_i and δl_{mean} Values for the NYABG Population sub-sample by sex

	Humerus	Radius	Ulna	Femur	Tibia	Fibula	Mean
Male	0.94		0.92	0.84	0.88		0.90
N	1		1	1	1		3
Female	0.98	1.03	1.02	0.97	0.98	0.91	0.98
N	5	2	4	5	2	1	5
Indeterminat	0.94	1.04	0.83	0.96	0.87	0.90	0.92
N	28	15	15	22	13	2	40
Mean	0.95	1.04	0.92	0.92	0.91	0.90	0.94
N	34	17	20	28	16	3	48

femur, tibia, and fibula (but not the ulna) have some of the lowest δl_{mean} values. The relatively high value for the fibulae has more to do with the exceptionally low representation of this element in the remains analyzed here. The fibulae that are present for analysis represent some of the taller (see discussion of stature below) and more mature members of the subsample, thus potentially skewing the value upwards.

Individual δl_{mean} values indicate that 73 percent (n=35) of the total subsample fall below the level of unity. Within this subsample, only one female has a δl_{mean} value in excess of unity, while thirteen indeterminate sex individuals and no males have δl_{mean} values that exceed unity. However, the lowest value for δl_{mean} (0.69) represents an approximately 6 month old infant (Burial 312). A close scrutiny of the aging and sexing database indicate that there were no discrepancies or errors made in the age assessment.

Overall, 79 percent of the individuals (n=38) have δl_{mean} values that are greater than 0.9. On the surface, this would seem to indicate that most children and young adults in this subsample had at least adequate nutrition to sustain growth. However, how standardized long bone measures influence our interpretation of environmental interactions with growth will be incorporated more fully in the following analyses of stature and pathologies.

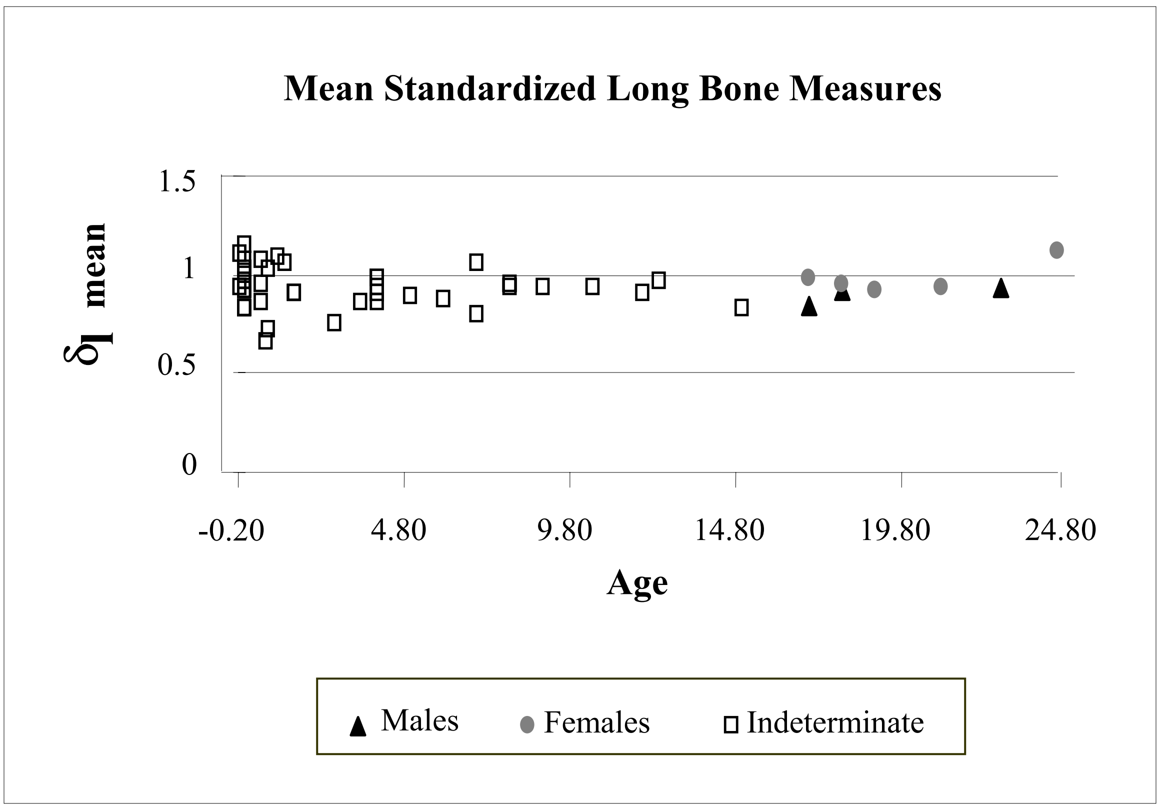

Figure 12.1: Mean Standardized Long Bone Measures

Stature Estimates

Stature estimates were calculated in a sex specific manner for all individuals represented by long bones whose biological age could be determined according to the criterion set forth above. Thus, stature estimates were calculated for a total of 129 individuals (males, n=54; females, n=34 indeterminate, n=41). Figures 12.2, 12.3, and 12.4 illustrate individual stature estimates for these NYABG individuals in relation to the select percentiles of the CDC/NCHS stature standards for males, females, and individuals of indeterminate sex, respectively. In these figures, male and female stature estimates are compared to the 25th, 50th, and 75th percentiles of the CDC growth standards, and individuals of indeterminate sex are compared to the male and female CDC male and female 50th percentiles. While all three Figures indicate a "normal" pattern of growth, especially as illustrated in Figure 12.4, they also indicate the presence of moderate-to-severe growth deficits at various points in the life span. Figure 12.2 identifies an overall growth deficit for nearly all the males in this mortuary subsample. When a close examination of males less than 25 years is undertaken by comparing Figure 12.2 and Table 12.8, it becomes apparent that all (n=3) males fall below the 10th percentile and would be classified with moderate-to-severe growth impairment. There are two males (66.7 percent) who do fall below the third percentile. Females younger than 25 years, as represented by Figure 12.3 and Table 12.9, have consistently higher stature estimates for assessed age. Sixty percent of all females (n=3) fall below the 50th percentile, while forty percent (n=2) fall at or above the 50th percentile. Two females (40 %) do fall below the 25th percentile in growth, which includes one female (20 %) who falls at the 10th percentile. However, females have a far greater percentage (n=3, 60 %) of individuals who fall within and above the range for normal growth, with one of these females (Burial 276) falling above the 90th percentile.

The representation presented in Figure 12.4, is provided as an evaluation of using a composite male/female regression formula for estimating the stature for individuals of indeterminate sex. No calculations of growth percentiles were undertaken for this segment of the population subsample.

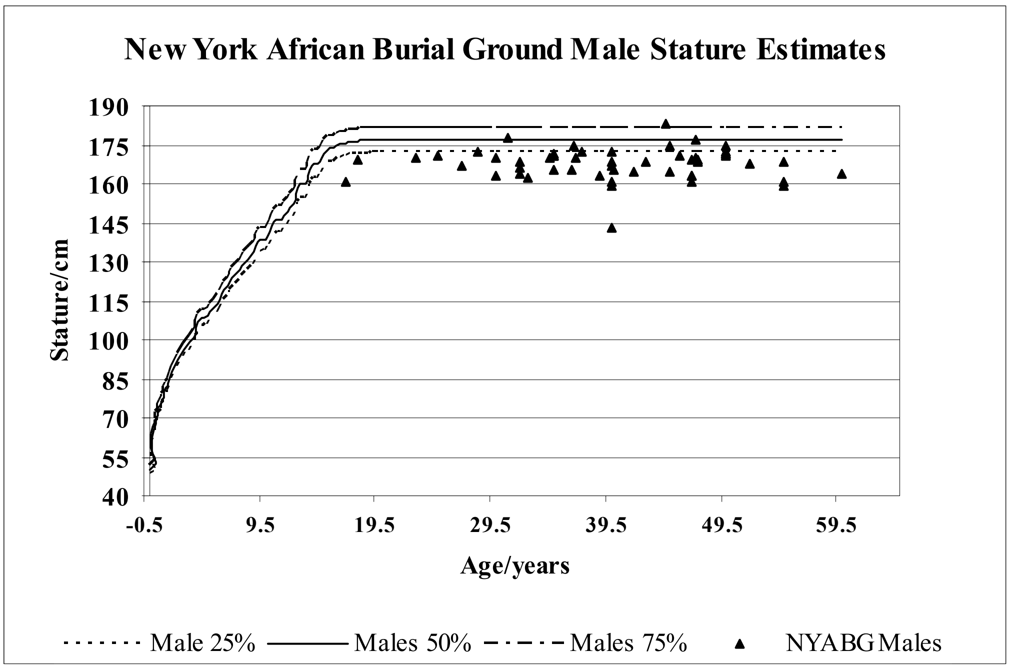

Figure 12.2: New York African Burial Ground Stature Estimates: Male

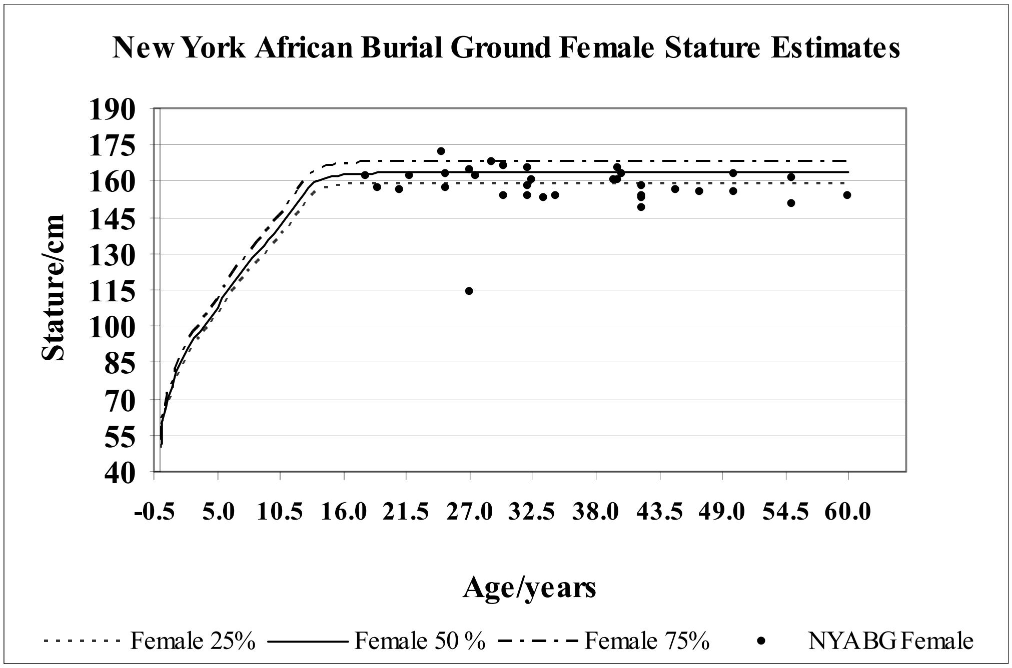

Figure 12.3: New York African Burial Ground Stature Estimates: Female

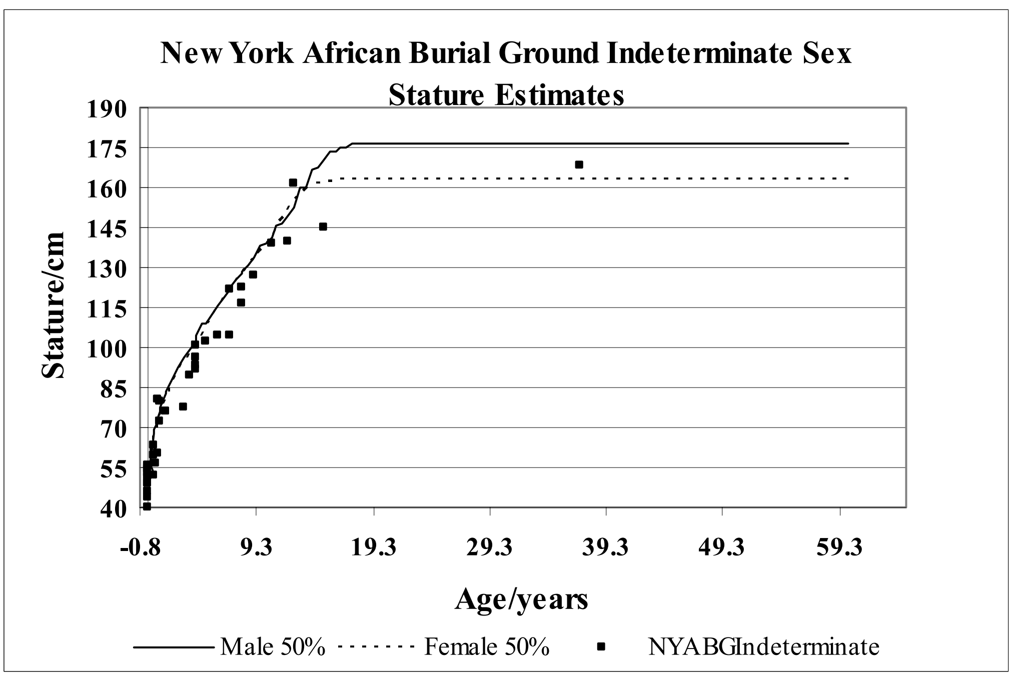

Figure 12.4: New York African Burial Ground Stature Estimates: Indeterminate Sex

However, by looking at the chart it is quite apparent that the individuals (predominantly infants and young children) were experiencing similar patterns in growth as the male and female standards, though the demarcation between those experiencing poor growth and those with normal or close to normal growth are more pronounced. As with the previous two figures, it is apparent that several individuals are falling well below the 25th percentile of growth (male or female standards). Overall, an initial assessment of these data, based on the figures and tables provided above, illustrate that stature, as a gauge of health and nutritional status, indicates females within this mortuary sample were healthier in relation to their male counterparts. Yet, as pointed out by Wood et al. (1992), this conclusion may be precipitous if considered a direct evaluation of individual risk of death due to underlying differences in frailty. A further evaluation of the sex specific stature estimates in relation to health will be taken up below.

Table 12.8: Male Stature Estimates and Growth Standard Percentile Rankings for Individuals less than 25 years of age only.

Burial #	Age	Stature	% Rank
96	17	161.09	2
427	18	163.19	9
343	22.8	170.14	2

Table 12.9: Female Stature Estimates and Growth Standard Percentile Rankings for Individuals less than 25 years of age only.

Burial #	Age	Stature	% Rank
259	18	162.03	49
205	19	156.65	24
122	21	156.35	10
383	21.75	161.69	50
276	24.5	158.17	94

The stature estimates provided above also need to be considered in relation to the standardized long bone measurements and pathology assessment before fully committing to this conclusion.

The relationship between the δl_{mean} values presented above and stature is illustrated in Figure 12.5. The δl_{mean} values are presented by sex and in relation to stature estimates. They further illustrate that on the whole, the population is not reaching its growth potential. Of the 71 percent (n=35) of the subsample that falls below the unity level, 3 (9 percent) are males, 5 (14 %) are females, and 27 (77 %) are individuals of young adolescents and children of indeterminate sex. This finding mirrors the 72 percent of the population subsample which fall at or below the 25th percentile for stature, considering that there were 39 immature individuals of indeterminate sex for which percentile rankings could not be assessed.

Correlations were undertaken to test the relationship between δl_{mean} and stature estimates or their percentile rankings to determine the validity of assessment of growth status based on the visual relationship between these two variables. The two-tailed test of δl_{mean} and stature estimates indicated there was a significant relationship between the two variables, something that could easily be predicted from Figures 12.1 and 12.4. However the test of relationship between δl_{mean} and percentile rankings of stature was significant at the $p<0.01$ level, with a correlation coefficient of 0.781 and an adjusted r^2 value of 0.601. The high but not perfect correlation between δl_{mean} values and percentile rankings is expected since both methods are founded on a common reference data set. However, the ability of each method to produce results that do not regress to the mean indicates that either or both of these methods can be utilized to probe issues of population health. The above analyses of growth status using standardized long bone measures and stature estimates indicate that the population was minimally not having its physical needs met. However, physical growth, as measured by stature or long bone growth, is not the only marker of nutritional status or health, nor is nutrition the only factor that influences growth. Therefore, the following section will present an analysis of data that relates to other skeletal indicators of nutritional stress, general infection and indicators of biomechanical stress.

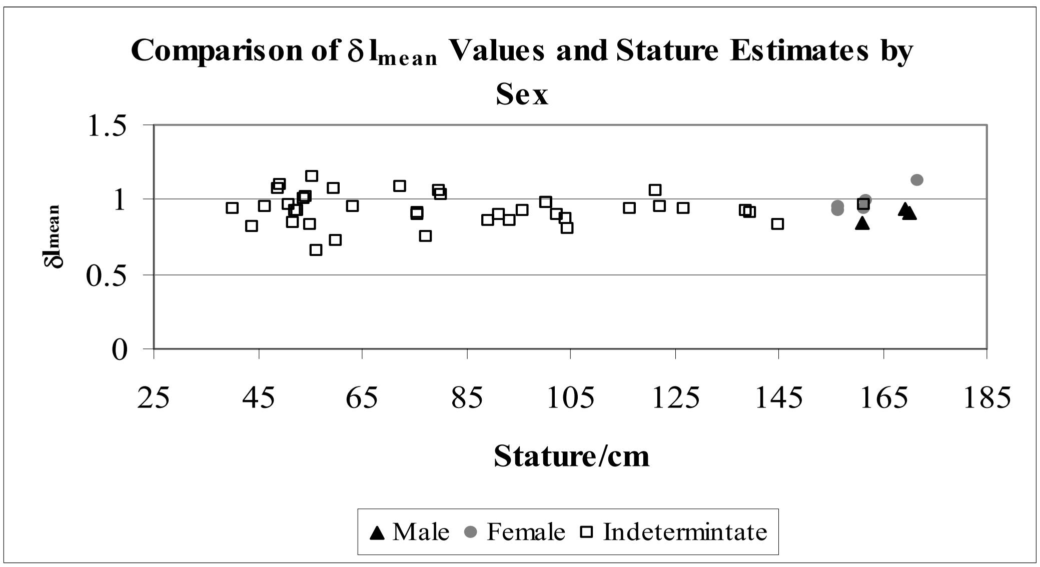

Figure 12.5: Comparison of Individual δl_{mean} Values and Stature Estimates by Sex

Pathological Assessments

The database available for pathological assessment of individuals from the NYABG contains over 16,000 entries related to pathology by type, element, aspect, and severity. Many of these entries are general codes that allow researchers to assess suites of pathologies for differential diagnosis, still a smaller percentage are codes that relate to specific disease or "abnormal" conditions. The analysis presented here relied on a survey of both types of pathological codes. The conditions that will be analyzed below are indicators of nutritional status, specifically pathologies related to anemias and generalized nonspecific infectious lesions, and biomechanical stress markers. The authors would like to remind readers that information presented in this chapter is restricted to a small subset of biologically immature individuals and may not reflect results presented in previous chapters (i.e., Chapter 10).

Nutritional and General Infection Indicators

Due to the synergy between nutrition and generalized infectious processes, this section will address both sets of pathologies. The first set of data to be considered is those associated most often with nutrition first and disease processes second. These data are related to anemia, specifically lesions found frequently in the craniofacial region known as porotic hyperostosis and their corresponding lesions in the eye orbit referred to as cribra orbitalia. Both orbital and cranial lesions will be referred to as porotic hyperostosis (PH) throughout the remainder of this chapter. Abnormal long bone morphology can also be attributed to nutritional deficiencies, such as anemia, rickets (vitamin D deficiency), and scurvy (vitamin C deficiency) and biomechanically induced stress during growth or over prolonged periods of time. These indicators of either nutritional status and/or biomechanical stress will also be considered below. However, as there are only limited ways in which bone can react to various insults (Ortner and Putschar 1981), infectious and dietary related lesions may be similar in appearance at the gross level of analysis, and can only be diagnosed at the microscopic or radiographic level. Thus, lesions characterized as reactive lamellar bone will be attributed to the category of generalized infectious processes, though undoubtedly some will eventually be diagnosed otherwise.

Nutritional Indicators

Porotic hyperostosis (PH) is most often associated with childhood nutritional deficiencies in iron during peak growth phases or may be attributed to genetic hemolytic disorders such as thalassemia or sickle cell anemia. The purpose of the analysis presented here is not to identify PH as iron deficiency anemia or as a hemolytic disorder; rather, it is to assess the presence of anemia-related lesions in relationship to against the health status of the infants, children, and young adults and its connections to their growth. Also, both nutritionally induced and inherited forms of anemias have negative consequences for growth, *vis a vis* their impact on cellular metabolism.

The individuals diagnosed with PH lesions in the subsample used in the current growth analysis are shown in Table 12.10. The number of PH/ ICH lesions per individual is represented as a means to complete individual frailty. In addition to PH, infantile cortical hyperostosis (ICH) may be a genetic condition or viral disease associated with anemia (Varma and Johny 2002) and is included in the table. Thirteen (27 %) of forty-eight individuals have PH lesions. Males represent 7 percent (n=1) of the affected individuals with sex assessments, which is 33 percent of all males in the population subsample (n=3). Females, in comparison, represent 14.2 percent (n=2) of the individuals with PH, and 40 percent of the total number of females in the subsample. Individuals of indeterminate sex (n=11) are young infants and children. Five of these children (45.5 %) are infants less than two years of age. In all, minimally 61 PH lesions are recorded for these 14 individuals. Given the small sample of individuals who could be sexed, the rate of lesions per individual (4.4) was calculated for the entire subsample. Tests for relationships between PH and δl_{mean} and percentile rankings of stature were made using the chi-square test. These tests were made for the total population subsample, as well as separately for age and sex groupings when the sample size permitted. The results of these chi-square tests are presented in Table 12.11. As can be seen in this table, the significant levels (p) of the chi-square statistic were well above a standard alpha of 0.05. Additionally, the power values computed to assess the possibility of type II (beta) errors (Hodges and Schell 1988:175) are also indicated in this table. The values for power presented in this table are those calculated assuming a large size effect (w = 0.50; also reported in Table 12.4).

Table 12.10: Occurrence of Porotic Hyperostosis and Infantile Cortical Hyperostosis in the NYABG Population sub-sample.

Burial	Age	Long Bone	Front	Pariet	Temp	Occip	Orb	Sphen	Max	Zyg	Tot. Path
Male											
343	22.8						2				2
Female											
205	18			2		1					3
122	21		1	4		1	2	1			9
Indeterminate											
186	0.00						2				2
64	0.63			2		1	1				4
225	0.75	6					2				8
91	1.00	2									2
252	1.50	6							2		8
7	4.00						2		2		4
55	4.00						2		2		4
138	4.00			2	2	1				2	7
39	6.00				2		2				4
35	9.00						2				2
368	12.00						2				2
Total (n)	14	3	1	4	2	4	10	1	3	1	61

Table 12.11: Chi-square Test Results for Relationship between PH and δl_{mean} and Percentile Rankings for Stature

Chi square test	Chi-square value	P
Total Population subsample (n=48; power = 0.9337)		
PH by δl_{mean}	4.168	0.654
PH by percentile ranking	7.352	0.499
Age Groups: 0<6 years (n=30; power = 0.7819)		
PH by δl_{mean}	4.541	0.604
PH by percentile ranking	5.284	0.727
Age Group: 6< 16 years (n=10; power = 0.3526)		
PH by δl_{mean}	0.476	0.788
PH by percentile ranking	1.667	0.435
Age Group: 16 < 25 years (n=8; power = 0.2930)		
PH by δl_{mean}	1.60	0.449
PH by percentile ranking	5.156	0.272
Sex: Male (n=3; power = 0.1393)		
PH by δl_{mean}	0.750	0.386
PH by percentile ranking	3.00	0.223
Sex: Female (n=5; power = 0.2010)		
PH by δl_{mean}	0.833	. 0.361
PH by percentile ranking	5.000	0.082
Sex: Indeterminate (n=40; power = 0.8854)		
PH by δl_{mean}	4.333	0.632
PH by percentile ranking	5.308	0.724

Generalized Lesions of Infection

An analysis of generalized or systemic infectious lesions produced very similar results as those for the relationship between PH and growth status. The pathological observations that constituted generalized infection as a variable were: lamellar reaction (active lesion), sclerotic bone (healed lesion), bone loss, and presence of reactive woven bone (concurrently active and healing lesion). The analysis presented here focuses on presence of infectious lesions in long bones as these skeletal elements contribute significantly to an individual's overall stature at maturity. As with PH/ICH lesions, the number of infections lesions per element per individuals is presented in Table 12.12 as a means to contemplate individual frailty. Table 12.12, demonstrates that it is possible to calculate that a total of twenty-five individuals (52 %) in this subsample (n=48) were diagnosed as having at least one lesion indicative of generalized infections. As with porotic hyperostosis, individuals of indeterminate sex represent the largest group to be diagnosed with generalized infectious lesions. Males, though, have the highest rate of lesion occurrence (15 per person), followed by females and indeterminate individuals with lesion rates of 14.7 per person and 10.9 per person, respectively. However, it should be noted that all males (n=2) and all females (n=3) with this diagnosis are over the age of 16 years, while all individuals of indeterminate sex (n=20) are under 16 years of age.

Table 12.12 also indicates that eight individuals (29.6 %) have 15 or more lesions at multiple osseous sites. A total of 20 individuals (74 %) have multi focal sites of infectious lesions in both upper and lower extremities; individuals could be classified as having systemic (possibly chronic) infection to one-third of the total population subsample. Chi square tests of relationship between infection and indicators of growth (percentile rankings and δ_{mean} groups) were computed for the total population subsample, by age group, and by sex. The results of these tests, shown in Table 12.13, demonstrate that infection is not related to δ_{mean} values or percentile rankings for stature. Additionally, a Fishers Exact chi-square evaluation of the potential relationship between anemia and infectious processes was undertaken. The results of this test were a majority of significance levels in excess of 0.100. The results of these analyses indicate that generalized infection does not contribute greatly to our understanding of the variation in growth status among members of this population's subsample nor the presence of PH lesions.

Table 12.12: Generalized Infectious Lesions as Diagnosed in Long Bone Skeletal Elements.

Burial#	Age	Humerus		Radius		Ulna		Femur		Tibia		Fibula		Total
		L	R	L	R	L	R	L	R	L	R	L	R	
Male														
427	18.00					2	2	2	2	2	2	3	3	18
343	22.80	1	1	1	1	1	1	1	1	1	1	1	1	12
Female														
259	18.00							1			1			2
122	21.00	3	3	3	3	3	3	3	3	3	3	3	3	36
383	21.75	2	2	1	1			3	3	1	1	1	1	16
Indeterminate														
117	-.13	1		1		1		1						4
42	.00			1		1		1	1	1	1			6
53	.50	1	1		1	1	1	1	1	1	1			10
108	.50	1	1	1	1	1	1							6
86	.75		2		2			2	2	3	3			14
225	.75	2	2	1	1	2	2	3	3	1	1	1	1	20
91	1.00			1	1	1	1	1	1					6
252	1.50	2	2		2		2	3	3					14
363	1.50	2	2	1	1	1	1	3	3					14
187	2.75	2	2	2	2	2	2	2	2	2	2	2	2	24
22	3.50	2	2	1	2	1	1	1	1	2	2		2	17
55	4.00	1	1	1	1	1	1	1	1	1	1	1	1	12
58	4.00	2	2	1						2	2	2	2	14
219	4.00	2	3		1		1	2	2	3	3	1	1	19
39	6.00	1	2					2	2	2	2	2	2	15
396	7.00			1	1			1	1					4
35	9.00					1	1							2
180	10.50							1	1					2
125	12.50									1	1	1	1	4
253	15.00	1	1					2	2					6
Total	**25**													**302**

Abnormal Bone Morphology

The presence of abnormal bone morphology, such as bowing, flared metaphyses, and "flattening" of long bone shafts, can be a result of nutritional deficiency, infectious process, or biomechanical stress. These factors can work singly or in combination to produce various forms of shape abnormalities. For instance, vitamin D deficiency (rickets) creates a physiological environment in which the absorption of calcium into bone matrix is inhibited. This failure leads to a state where the structural integrity of the cortical bone is weakened and the biomechanical stress of load bearing can cause bowing of the long bones. Symmetry of pre-mortem long bone abnormal shape could not be assessed due to the unequal representation of long bones for most individuals.

There were “a total of” forty individuals (83 %) of the population subsample that were diagnosed with some form of pre-mortem abnormal shape in one or multiple long bones. Twelve individuals (25 %) were diagnosed with either platycnemia or platymeria (flattening of the tibial and femoral shafts, respectively). Eighteen (37.5 %) were also diagnosed with bowing of one or more long bone shafts, while thirty-six (75 %) individuals were diagnosed with flaring of the metaphyses of one or more long bones. Table 12.14 indicates the distribution of these pathologies for the total population subsample by age and by sex.

Potential relationships between shape abnormality and anemia, infection, and growth status were statistically tested using chi square analyses. The results of these tests indicate that there is no relationship between long bone shape abnormalities and anemia or δl_{mean} grouping values. The only significant association was between bowing and infection in children $> 0 \leq 6$ years ($n = 30$; $p = 0.003 < 0.05$).

As was noted above, these morphological variables bridge the three categories of pathologies being analyzed in this chapter. The following section will proceed with an analysis of biomechanical stress indicators in an attempt to more fully elucidate the complex relationships between these factors.

Table 12.13: Chi-square Test Results for Relationship between Infectious Lesions and δl_{mean} and Percentile Rankings for Stature

Chi-square test	Chi-square value	P
Total Population sub-sample (n=48; power = 0.9337)		
Infection by δl_{mean}	9.043	0.171
Infection by percentile ranking	9.997	0.265
Age Groups: 0<6 years (n=30; power = 0.7819)		
Infection by δl_{mean}	30.000	0.414
Infection by percentile ranking	12.254	0.140
Age Group: 6< 16 years (n=10; power = 0.3526		
Infection by δl_{mean}	10.000	0.350
Infection by percentile ranking	1.667	0.435
Age Group: 16 < 25 years (n=8; power = 0.2930)		
Infection by δl_{mean}	8.000	0.333
Infection by percentile ranking	5.156	0.272
Sex: Male (n=3; power = 0.1393)		
Infection by δl_{mean}	3.000	0.083
Infection by percentile ranking	3.000	0.223
Sex: Female (n=5; power = 0.2010)		
Infection by δl_{mean}	1.875	0.171
Infection by percentile ranking	2.917	0.233
Sex: Indeterminate (n=40; power = 0.8854)		
Infection by δl_{mean}	6.722	0.347
Infection by percentile ranking	10.250	0.248

Table 12.14: Distribution of Abnormal Long Bone Shape in the Total NYABG Population sub-sample by age and sex

Age	Flattening		Bowing		Flaring	
	n	percent	n	percent	n	percent
Total Subsample	12	25	18	37.5	36	75
0 < 6 years	1	3.3	9	30	25	83
6 < 16 years	5	50	6	60	7	70
16 < 25 years	6	75	3	37.5	4	50
Males	3	100	1	33.3	2	66.7
Females	3	60	2	40	2	40
Indeterminate	6	15.0	15	37.5	32	80

Biomechanical Stress Indicators

Indicators of biomechanical stress can manifest themselves skeletally in a variety of ways. One is the absolute change in morphology of a skeletal element, as was mentioned above. Many biomechanical stress indicators are generally "built" over time and are often the result of interactions between load bearing and/or repetitive motion and other factors affecting bone metabolism. In some instances, the factor affecting bone metabolism is due to natural processes of metabolic slowdown related to aging. This is often the case with age-related osteoarthritis–years of "living and doing" manifest as symptoms of arthritis in increasing frequency as individuals age. Arthritis in younger adults and children may be a result of a variety of disorders such as juvenile rheumatoid arthritis and its related autoimmune disorder Lupus. Yet, it may also be a result of intense or increased physical activity (load bearing and repetitive actions) at points in the life span when bone (and cartilage) is undergoing rapid rates of remodeling due to growth cycles.

Intensified or increased physical activities can also leave their mark by accentuating points of muscle insertions or origins on bone (hypertrophies). These tend to be the result of long term biomechanical stress on those areas. However, acute events of intense physical activity can result in the avulsion of bone at the site of muscle and ligature insertions (enthesopathy and arthropathy, respectively). Fractures are another class of acute events related to biomechanical stress. Whether a fracture is the result of purposeful or inadvertent action, the result of the action is that bone is subject to a biomechanical force that exceeds its capacity to maintain structural integrity.

With this in mind, the NYABG pathology database was probed for occurrences of biomechanical indicators of stress in long bones, specifically looking for occurrences of fractures, arthritis, enthesopathy/arthropathy, and hypertrophy in individuals under the age of 25 years. It should be noted that project Osteologists paid close attention to discerning the differences between bone irregularities resulting from normal growth processes and those directly attributable to acute and/or chronic biomechanical stressors.

A total of nineteen people (39.5 %) in the population subsample were diagnosed with these biomechanical stress indicators. Table 12.15 provides a summary of all individuals who were represented by at least one occurrence of any of these four biomechanical stress indicators. The number one (1) in a column designates the occurrence of at least one site of a specific indicator, though many individuals were diagnosed as having multiple sites of biomechanical stress. This table indicates that five

(26.3 %) of the individuals were diagnosed with fractures. Approximately 42 percent of the population subsample was diagnosed as having arthritis, while sixteen

Table 12.15: Distribution of Individuals with Biomechanical Stress Indicators by age and sex in the NYABG Population sub-sample

Burial	Age	Fracture	Arthritis	Hypertrophy	Enthesopathy
Male					
96	17.00			1	
427	16.50				1
343	22.8		1	1	
Female					
205	18.00	1	1	1	1
259	18.00	1	1	1	1
122	21.00		1	1	1
383	21.75			1	1
Indeterminate					
58	4.00			1	
138	4.00			1	
219	4				1
39	6.00		1	1	1
244	7.00			1	1
396	7.00			1	
95	8.00		1	1	1
405	8.00			1	
180	10.50	1		1	
368	12.00			1	
25	12.5	1	1		
253	15.00	1	1	1	1
Total (n)	19	5	8	16	11

(84.2 %) and eleven (57.9 %) individuals were recorded as having hypertrophies or enthesopathies, respectively. What is striking about this occurrence of biomechanical stress indicators is that a total of eleven children (57.9 %) under the age of 16 years have been diagnosed with fractures, arthritis, hypertrophies, or enthesopathies. Also eight of these children are between the ages of four and ten years. The co-occurrence of hypertrophic attachments and enthesopathy is more prevalent in females (n=4, 100%), while males have a 50 percent (n=1) co-occurrence followed by indeterminate individuals with 33.3 percent (n=4).

Statistical tests of observable relationships (Table 12.16) between the three indicators of biomechanical stress were made. Due to the low subsample size for fractures they were not included in this, or any of the following analyses. The results of Fisher's Exact chi square analyses provided in Table 12.16 demonstrate significant relationships in the pattern of co-occurrence of these variables ($n = 48$; $p < 0.05$). Statistical analysis of these biomechanical stress indicators in relation to growth status, PH, generalized infectious lesions, and abnormal shape variables were also tested. The results of statistically significant relationships for the total population subsample (n=48) were between: hypertrophy and long bone flattening ($\chi^2 = 9.341$, $p = 0.004 < 0.05$); arthritis and long bone flattening ($\chi^2 = 13.642$, $p = 0.001 < 0.05$); enthesopathy and long bone flattening ($\chi^2 = 11.361$, $p = 0.002 < 0.05$); hypertrophy and bowing ($\chi^2 = 4.713$, $p = 0.033 < 0.05$); and enthesopathy and bowing ($\chi^2 = 4.159$, $p = 0.047 < 0.05$). Among individuals of indeterminate sex, statistically significant relationships were also found among a small set of variables. These relationships are: hypertrophy and long bone flattening (χ^2 = 6.536, p = 0.026< 0.05) and hypertrophy and long bone bowing (χ^2 = 6.009, p = 0.020 < 0.05). When considering the relationships between these variables by age grade, only stature ranking (percentile) and enthesopathy (χ^2 = 9.000, p = 0.011 < 0.05) in children ≥ 6< 16 years, and δl_{mean} and enthesopathy (χ^2 = 8.000, p = 0.018 < 0.05) in subadults/young adults ≥ 16< 25 years exhibited statistically significant results. The overall relationships among long bone flattening and arthritis, hypertrophy, and enthesopathy may indicate that this particular form of abnormal bone shape is more likely to result from biomechanical stress rather than nutritional insufficiency. Additionally, the relationship between enthesopathy and δl_{mean} values and stature ranking in children over the age of 6 years is a strong indicator that childhood labor was impinging upon long bone growth.

Table 12.16: Results of Chi-square Tests of Relationships between Biomechanical Stressors

Chi-square Test	Chi-square	p
Arthritis by hypertrophy	15.157	0.0001
Arthritis by enthesopathy	19.899	0.0001
Hypertrophy by enthesopathy	19.475	0.0001

Craniosynostosis

The presence of craniosynostosis was observed in 15 individuals of the 48 individuals under the age of 25 years (31.3 percent) that comprise the subsample for analysis in this chapter. The suture(s) involved sex, and age of each of these individuals is provided in Table 12.17. As can be seen in this table, 12 of the individuals (80 %) are 6 years of age or older. When considering the prevalence of craniosynostosis in relation to growth, infection, nutrition, and biomechanical indicators, several evocative relationships were revealed. Table 12.18 provides only the statistically significant results between these variables and craniosynostosis. When these results are reviewed, one must remember that all individuals of indeterminate sex in the population subsample are under the age of 16 years. Several significant relationships ($p < 0.05$) exist between craniosynostosis and infectious, nutritional, and biomechanical indicators at the level of the total population subsample. However, the relationships observable among a large segment of the youngest members of this subsample indicate that minimally the presence of craniosynostosis in any given individual can be exacerbated by chronic or acute exposure to biomechanical, nutritional, and/or infectious stressors. In particular, nutritional and biomechanical stressors may accelerate or even cause the expression of this particular developmental pathology.

Table 12.17: Individuals with Craniosynostosis by Suture(s)

(S= spheno, F=frontal, T= temporal; P=parietal)

Burial	Age	Coronal		Sagittal	Lambdoid		SF		SFT		SFTP		Total Sutures
		L	R		L	R	L	R	L	R	L	R	
Males													
427	18			x									1
96	17			x	X	x							3
343	18						x						1
Females													
122	21	x	x	x							x	x	5
383	21.75	x	x	x									3
Indeterminate													
91	1			x									1
252	1.5			x	X								2
58	4		x					x					2
39	6		x	x	X			x					4
95	8			x				x					2
405	8			x	X								2
35	9		x	x	X	x				X			5
180	10.5			x	X	x							3
368	12							x					1
253	15	x					x						2
Total (n)	15	3	5	11	6	3	2	4		1	1	1	

Table 12.18: Chi-square Test Results for Relationship between Craniosynostosis and Biomechanical, Nutritional, and Infectious Indicators

Chi-square test	Chi-square value	P
Total Population subsample (n=48; power = 0.9337)		
Craniosynostosis by arthritis	8.828	0.006
Craniosynostosis by hypertrophy	12.738	0.001
Craniosynostosis by enthesopathy	6.967	0.013
Craniosynostosis by flattening	14.255	0.0001
Craniosynostosis by bowing	11.953	0.001
Craniosynostosis by infection	3.948	0.046
Age Groups: 0<6 years (n=30; power = 0.7819)		
Craniosynostosis by bowing	7.778	0.021
Sex: Indeterminate (n=40; power = 0.8854)		
Craniosynostosis by hypertrophy	14.400	0.001
Craniosynostosis by arthritis	5.926	0.042
Craniosynostosis by flattening	6.536	0.026
Craniosynostosis by bowing	10.276	0.002

Discussion

Analyses of standardized long bone measures and stature estimates of the NYABG sample demonstrate that environmental stressors impacted overall growth. Goode et al. (1993) proposed that standardizing measures of long bone length would facilitate intra- and interpopulation comparisons of growth and health. Within this population subsample, neither nutritional, generalized health, nor biomechanical indicators of environmental stressors were associated with low δl_{mean} values presented in Table 12.7. Sciulli (1994) has published the only comparable data for five Native American populations in the Ohio River Valley (3000BP-300BP). Table 12.19 compares the values calculated for the NYABG sample (n=48) to those presented by Sciulli (1994). While the samples compared in this table exhibit temporal heterogeneity, they all show the differential impact that δl_i have on δl_{mean} values. Also, all skeletal series illustrate that the long bones of the lower extremity, generally the femur, tend to have the lowest δl_i values within each population. While there are considerable differences between δl_i values, patterns of long bone growth are quite similar when subsample size is taken into consideration.

Table 12.19: A Comparison of NYABG δl_i and δl_{mean} Values with those of five Native American Populations (Sciulli 1994)

	δl_i						
	Humer	**Radius**	**Ulna**	**Femur**	**Tibia**	**Fibula**	δl_{mean}
NYABG (18th century)	0.95	1.04	0.93	0.93	0.90	0.90	0.94
n	34	17	20	31	14	3	50
Archaic (3000 years BP)	0.92	0.94	0.91	0.88	0.92	0.89	0.90
n	24	15	15	24	16	7	32
Pearson (850 years BP)	0.93	1.00	0.98	0.90	0.98	0.96	0.93
n	26	19	20	45	38	23	59
Sunwatch (800 years BP)	0.87	0.87	0.87	0.82	0.86	0.85	0.86
n	63	58	55	57	54	48	77
Monongahela (600 years	0.89	0.91	0.92	0.85	0.87	0.87	0.89
n	43	39	32	43	38	24	61
Buffalo (300 years BP)	0.87	0.86	0.90	0.84	0.85	0.85	0.88
n	28	22	19	35	25	10	43

This finding demonstrates that the calculation of standardized long bone measures may be quite useful, as Goode et al. (1993) predicted, for comparisons of growth when the goal is to assess variation that disease has on growth. As these authors noted, it is necessary to broaden the definition of disease within this context. While Goode-Null (2002) promoted the inclusion of trauma, this study has included other biomechanical stress indicators that are more frequently associated with chronic or intense physical activity as a means of investigating labor-related activities of children.

The estimation and assessment of stature for the NYABG sample indicate that most of young adults and children were falling well below the 25th percentile of the CDC/NCHS height for age standards. When the possible factors that may have influenced the overall poor growth status of these individuals are considered, none of the variables representing nutritional status, generalized health status, or biomechanical stress proved to have a significant relationship with estimated stature for the population subsample. Another factor that must be considered is that error in age estimation of young individuals could have influenced the application of regression formula. These factors could either over or underestimate stature calculations depending upon which error was made. However, close examinations of dental aging scores did not demonstrate errors in the extrapolation of mean dental ages. Additionally, the age ranges for each of the juvenile regression equations are generally broad enough to capture minor errors in dental age estimation.

Steckel (1996) provides the only comparable data for enslaved individuals under age 25 years. Reporting on stature estimates taken from ship manifests supplying the Antebellum South (1820-1860), he provides mean stature calculations for enslaved males and females from 4.5 years of age through adulthood. A comparison of the NYABG stature estimates and those reported on by Steckel are provided in Figures 12.6 and 12.7

for males and females respectively. It should be noted that the values at age 25 years in both figures actually reflect adult stature estimates for both the NYABG population and those individuals comprising Steckel's sample. This comparison indicates that there are no significant differences between the NYABG and antebellum South samples of enslaved Africans and African Americans. The lack of significant differences in the two population samples suggests that 1) enslavement was equally detrimental to the health of individuals (as reflected by growth status) in the North and in the South, and 2) the regression formula used to estimate stature for the NYABG juvenile remains provides an accurate reflection of the growth status of these individuals.

While growth status can stand alone as an indicator of population health and nutritional status, it is the result of a complex set of interactions among nutritional intake, disease processes, and energy expenditure during physical activity. Thus, the fact that the majority of independent nutritional and health indicators were not significantly correlated with growth status within the NYABG population subsample warrants further discussion. Nutritionally, minimally one-quarter sample had experienced an episode of anemia. Interestingly, of all lesions diagnosed and identified as PH, only one individual, an approximately 8-month old infant of indeterminate sex (Burial 64), had lesions coded as active only. All other individuals in the population subsample have PH lesions noted as healed and were, therefore, not actively experiencing iron deficiency at the time of their death. This situation may explain why there was no correlation between presence/absence of PH lesions and stature, percentile of growth ranking, or δl_{mean}. Those individuals who are in the mortuary population that had experienced an anemic episode had already recovered or begun to recover their growth–they either had experienced or were experiencing a catch-up phase of growth at the time of their death. This possibility is not one that can be confirmed or rejected based on the data available from a cross-sectional view study.

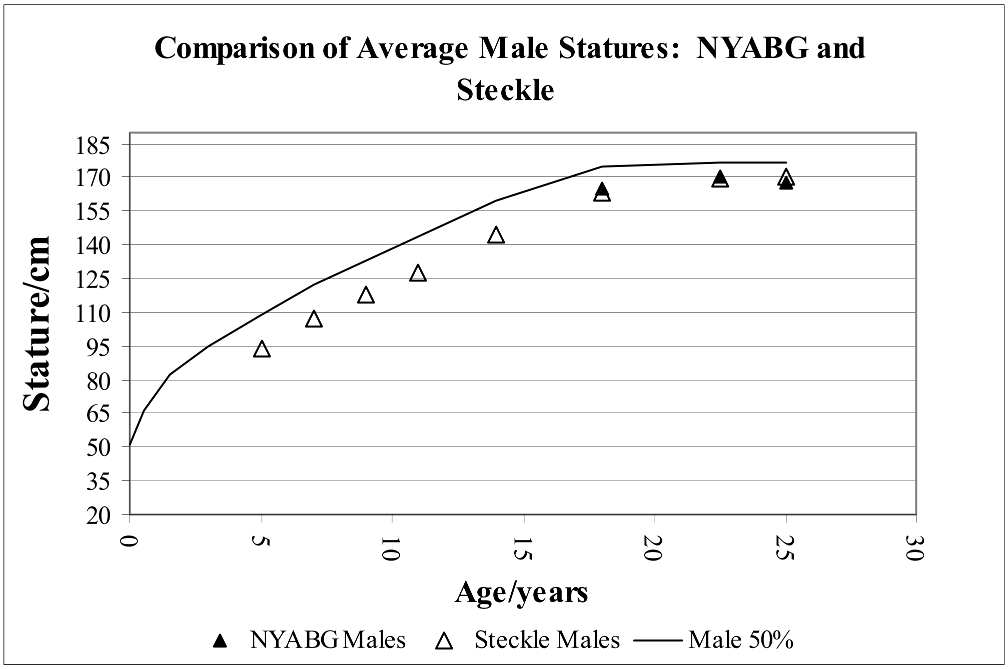

Figure 12.6: Comparison of Average Male Statures: New York African Burial Ground and Steckel

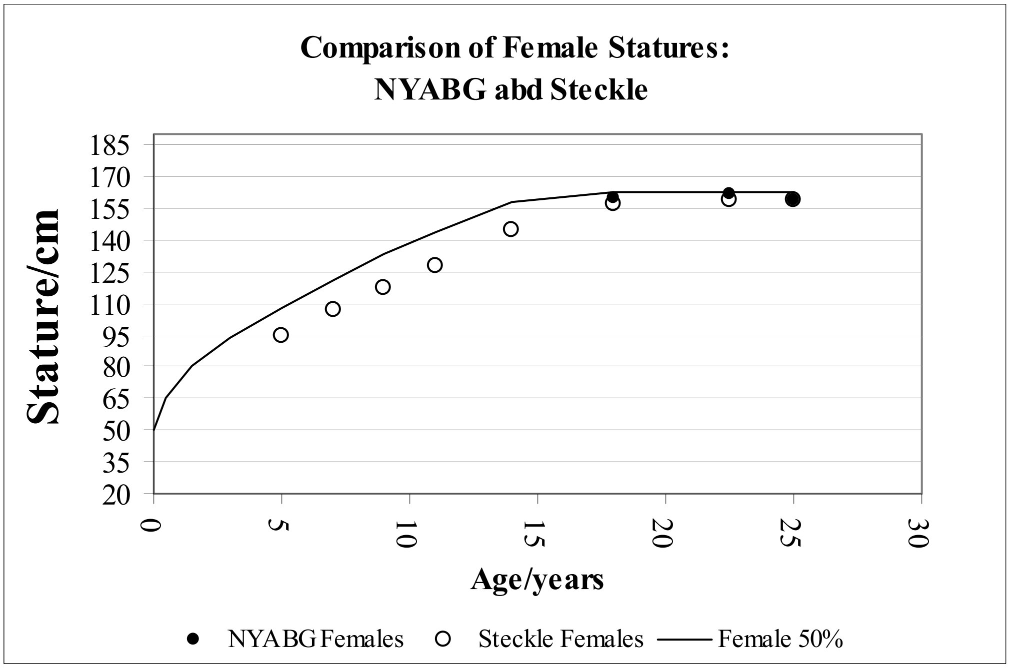

Figure 12.7: Comparison of Average Female Statures: New York African Burial Ground and Steckel

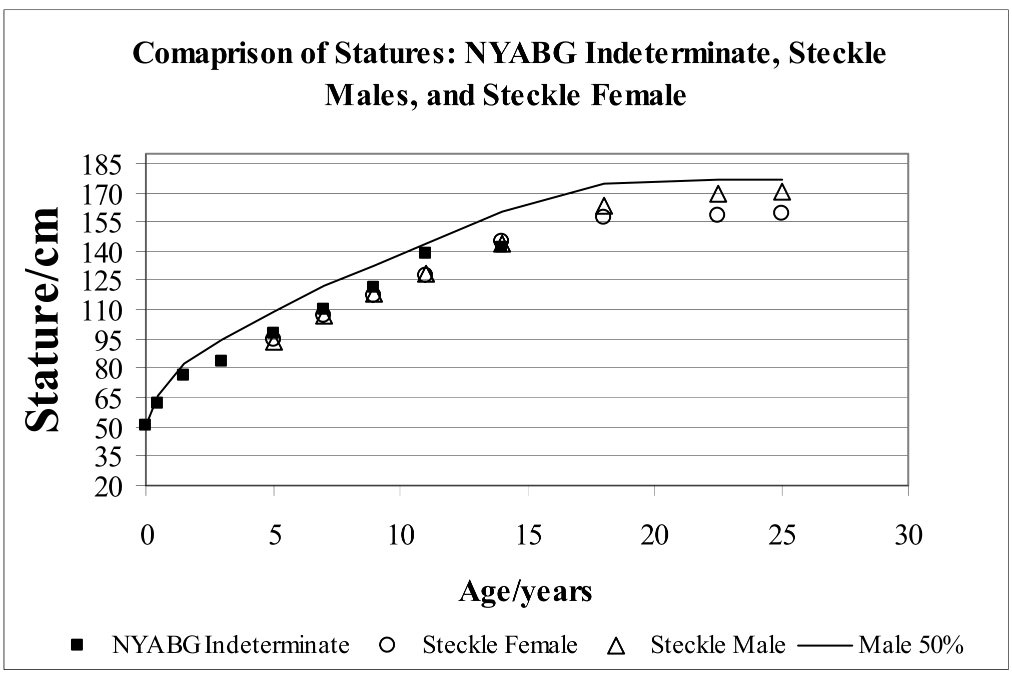

Figure 12.8: Comparison of Statures: New York African Burial Ground Indeterminate, Steckel Male and Steckel Female

The relationship between growth and generalized lesions makes quite apparent that more than half of these young people (52 percent) experienced bouts of chronic infection. However, there were no significant relationships between growth status and the rates of infectious lesions. Nor was there a significant relationship between rates of PH and generalized infectious lesions. This absence is contrary to Rankin-Hill's (1997) findings for the FABC population in Philadelphia where the co-occurrence of these two pathologies was significant at the $p < 0.01$ level. Again, this finding may be due to the vast majority of PH lesions in the NYABG sample being healed lesions in contrast to the 40 percent active rate for PH lesions in the FABC sample. This difference in active versus inactive PH lesion frequencies may actually address the issue of heterogeneous risk of death within and between populations by indicating differential levels of individual frailty, and warrants future consideration.

Statistical tests of abnormal bone shape demonstrated no significant associations with PH in the total population subsample, by age, or by sex. However, bowing of the long bones did have statistically significant relationships with infection in children in the $> 0 \leq 6$ year cohort.

The results from the analysis of biomechanical stress indicators did not demonstrate any significant relationship with growth status. However, several thought-provoking patterns did emerge from this analysis. First, approximately 40 percent (n=19) of the population subsample demonstrated some form of biomechanical stress–with all individuals exhibiting at least one area of hypertrophic muscle attachment– while 16.6 percent and 23 percent had been diagnosed with arthritis and enthesopathies, respectively. In general, there were more females than males with biomechanical stress indicators. However, there were also seven children, biologically aged from four to eight years, who exhibited hypertrophic attachment–three of whom also had at least one enthesopathy and one who also had arthritis. Given the care that was taken to not inadvertently diagnose normal developmental features of the muscle attachment sites as hypertrophic and the co-occurrence of hypertrophy with arthritis and enthesopathies, these individuals are a clear example that enslaved children in New York City engaged in strenuous physical activities.

Chi square tests for associations between these biomechanical stress indicators and abnormal bone shape in the total population subsample (see Table 12.20) did reveal that flattening was related to all three biomechanical variables. This analysis supports a conclusion that long bone shaft flattening should be considered another indicator of biomechanical stress, even in young individuals. Flattening of the long bones was also associated with hypertrophies ($\chi^2 = 6.536$, $p = 0.026 < 0.05$) in indeterminate individuals, as was bowing and hypertrophies ($\chi^2 = 6.009$, $p = 0.020 < 0.05$). Biomechanical stress indicators were not related to the occurrence of PH lesions in the total population subsample, by age, or by sex.

Table 12.20: Results of Chi-square Tests of Relationships between Biomechanical Stressors and Abnormal Flattening of Long Bones

Chi square Test	Chi square	P
Hypertrophy by flattening	9.341	0.004
Arthritis by flattening	13.642	0.001
Enthesopathy by flattening	11.361	0.002

Conclusion

The analysis of growth and development presented above does not provide a clear picture of cause effect in relation to growth status. This chapter used bivariate statistical analyses to affirm that the relationships between disease, nutrition, biomechanics, and the underlying genetics/biology of growth and development are complex. However, this bivariate analysis does allow a few general conclusions:

1. Indicators of growth status, particularly stature rankings, clearly indicate a population that was not reaching its growth potential. Given that growth status is often used as a proxy for overall population health, it is not injudicious to put forth that the overall health status of the NYABG population was poor.
2. Evidence of biomechanical stressors in individuals as young as four years indicates that children were participating in strenuous activities. Given that this population is known to be composed of enslaved Africans and African Americans and supported by historical documentation (see Franklin 1967; Kruger 1985), it is more likely that these youngsters were engaged as laborers.
3. Relationships observed between the presence of craniosynostosis, nutrition, biomechanics, and infection indicate that development was affected negatively by its social milieu. This point is of particular concern, as impairments in developmental processes may have long term effects on the reproductive capabilities of individuals within any population.

Notes

[1] Goode-Null (2002) recommends using the broader definition of "disease" that incorporates trauma, rather than the more restrictive definition used by Goode et al. (1993) which focuses on infectious events. Goode-Null also notes that this method provides an opportunity to verify age assessment in individuals with extreme δl_i or δl_{mean} values.

[2] Due to the criteria used for constructing this baseline sample, there may be some inconsistencies in the ages reported for some individuals between this and other chapters when results of the analysis are presented and discussed.

[3] Based on an examination of the supporting data included in the original text, the lack of standard errors of the estimates is most likely due to the extremely small values for this measure.

[4] Specifically, the data sets are the product of the United States Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Health Statistics, Data Services.